



Augmenting Conceptual Design Trajectory Tradespace Exploration with Graph Theory

AIAA Space 2016

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Jacobs ESSSA Group

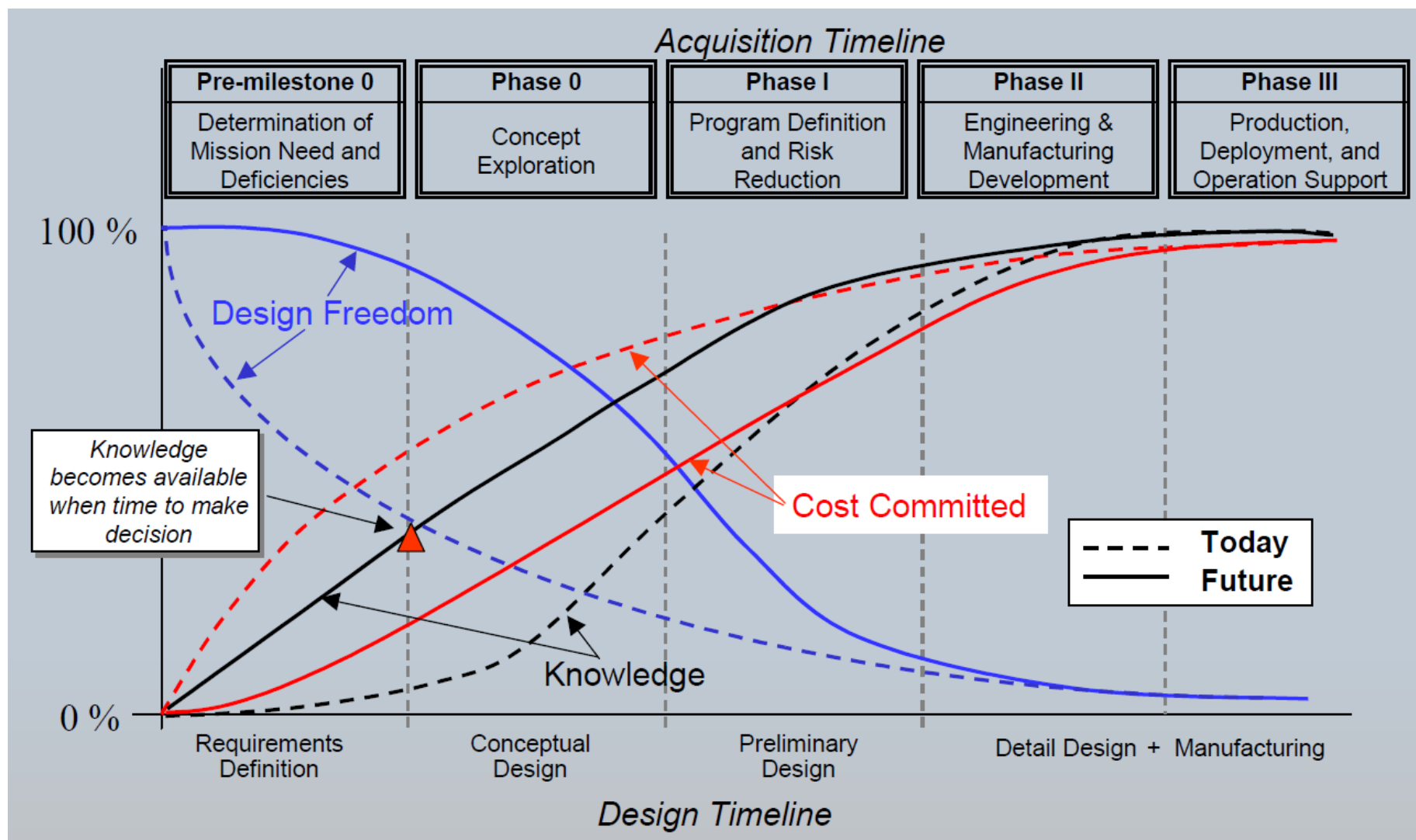
Stephen Edwards, Michael Steffens

Georgia Institute of Technology





Motivation





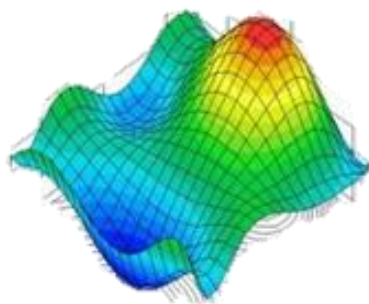
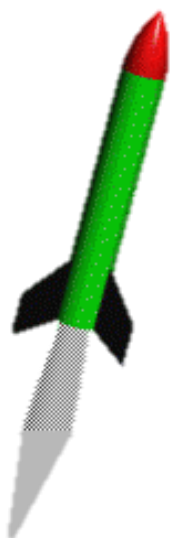
Motivation





Motivation

Ease of Use

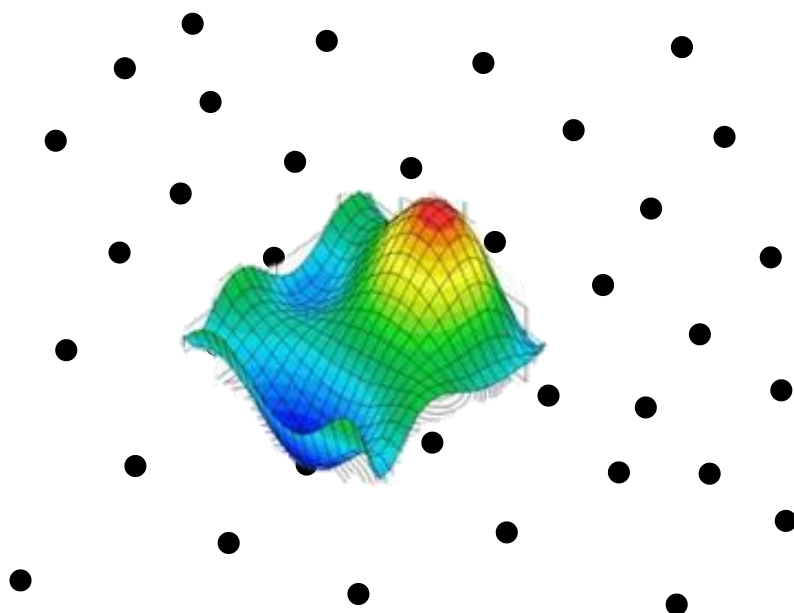


Fidelity



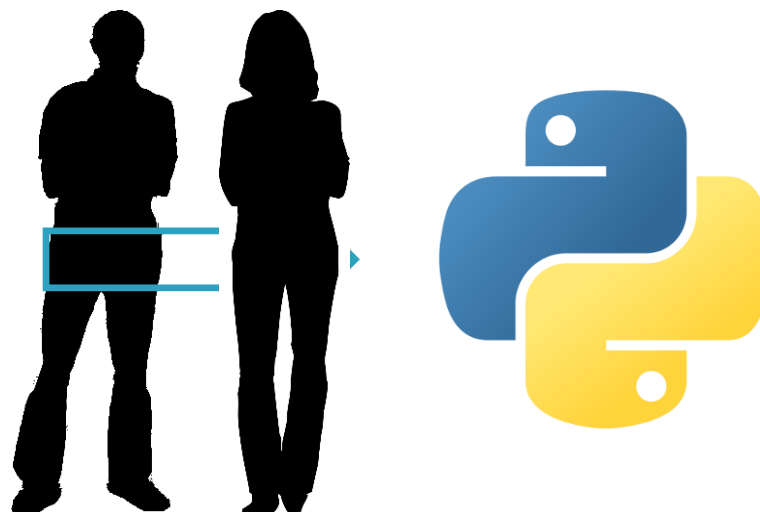


Motivation



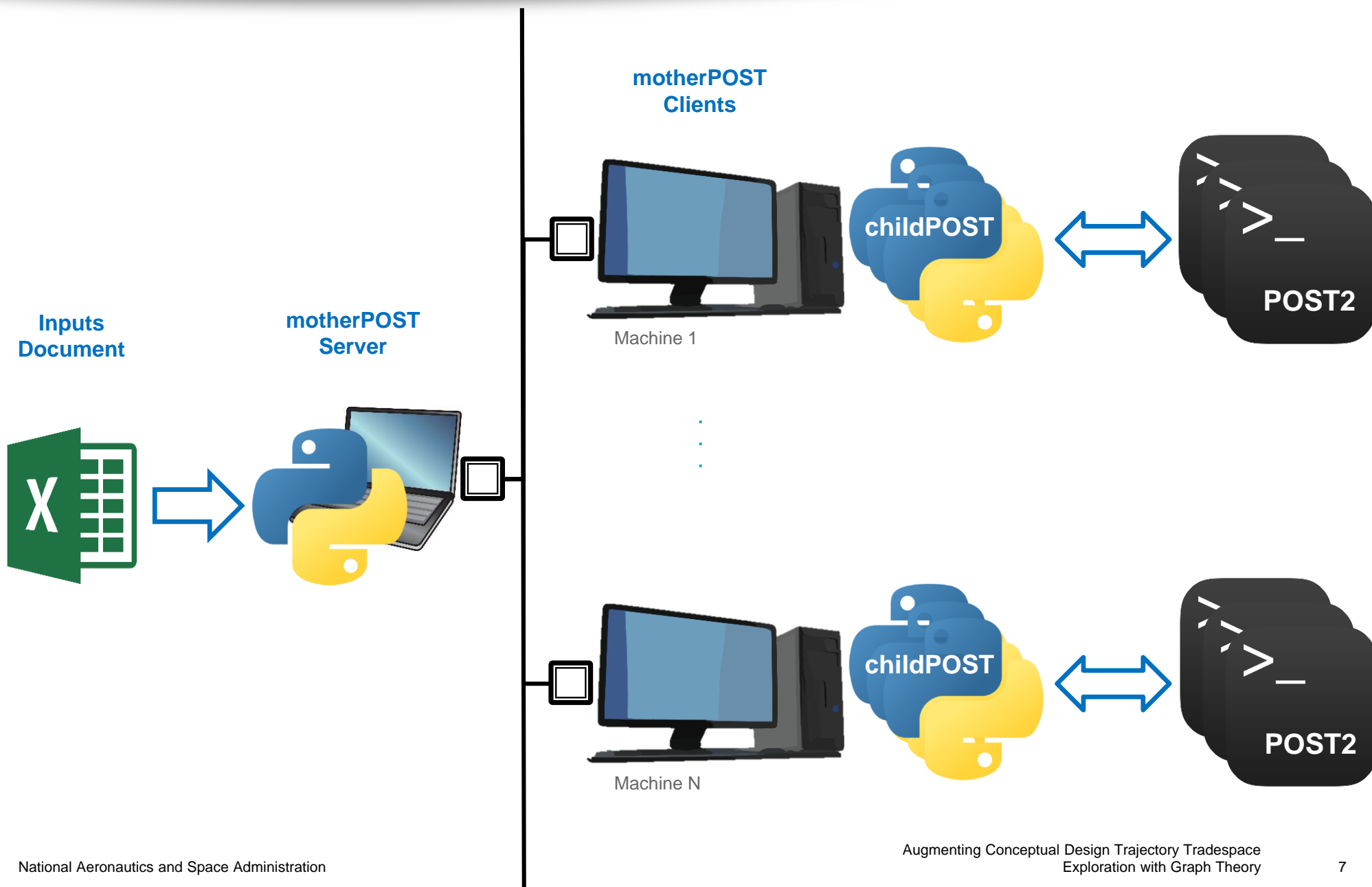


Motivation





multiPOST

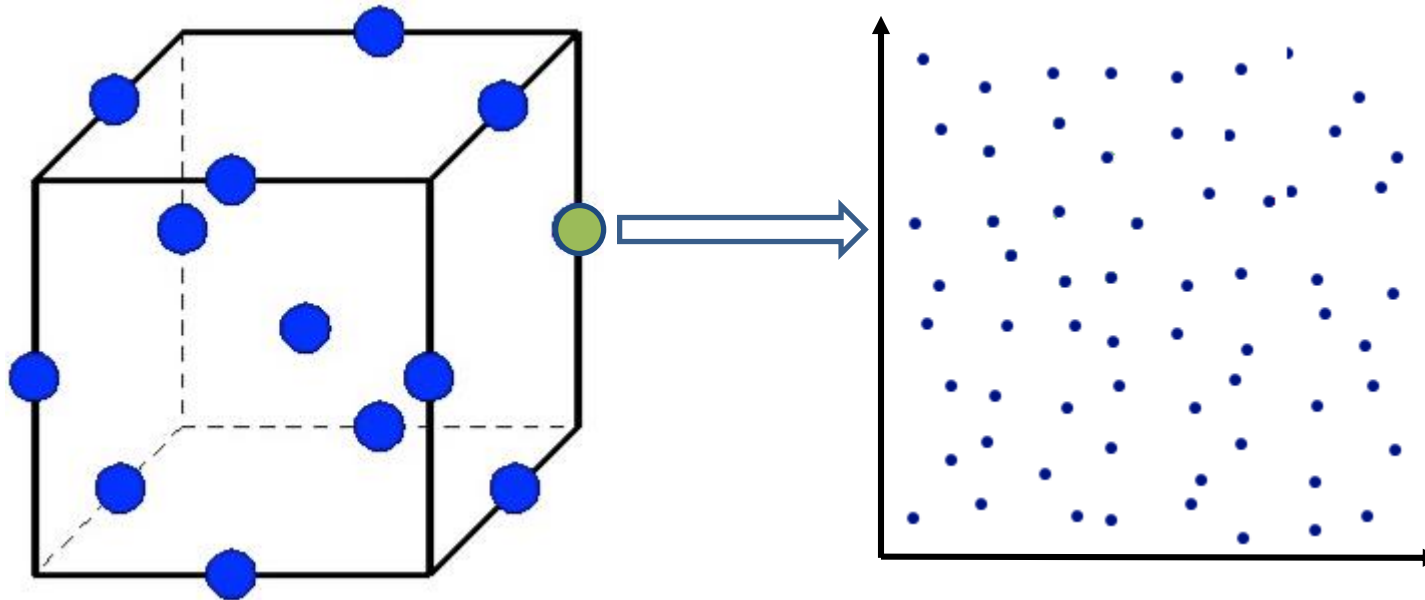


Repetitions Method

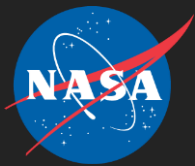
- ◆ Repetitions are generated by pairing a single case from the Vehicle-Level DOE with a number of randomly selected Steering-Level input vectors

$$\text{Vehicle Level: } \vec{v} = \begin{bmatrix} \text{masses} \\ \text{engines} \\ \text{enviro.} \end{bmatrix}$$

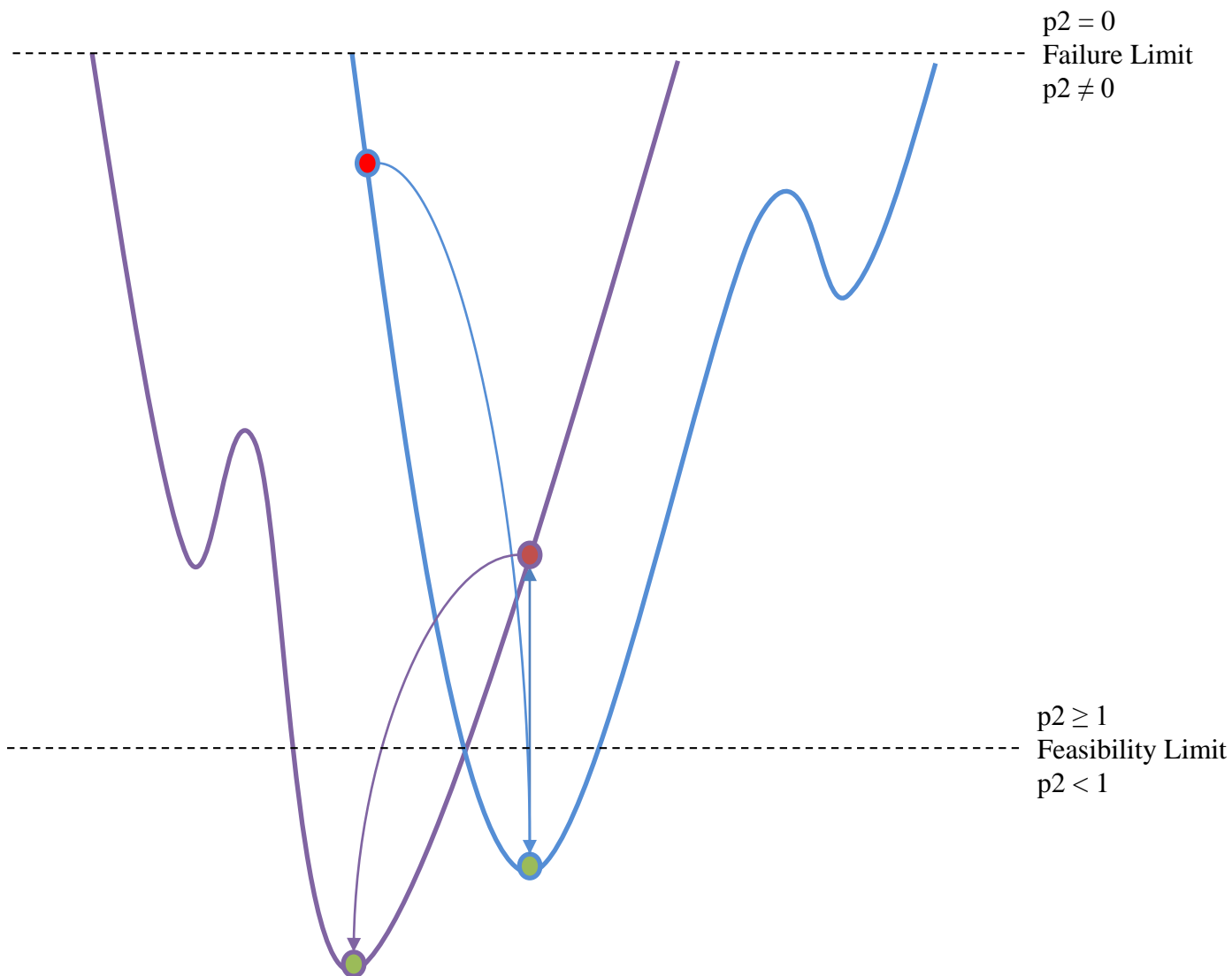
$$\text{Control Level: } \vec{u} = \begin{bmatrix} \text{pitch rates} \\ \text{launch azi.} \\ \text{etc.} \end{bmatrix}$$





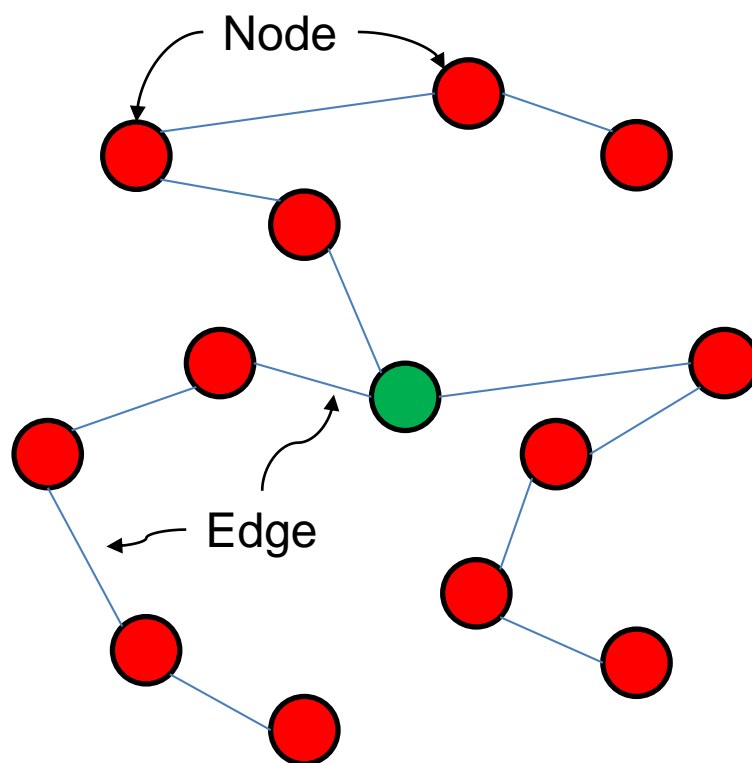


Chaining



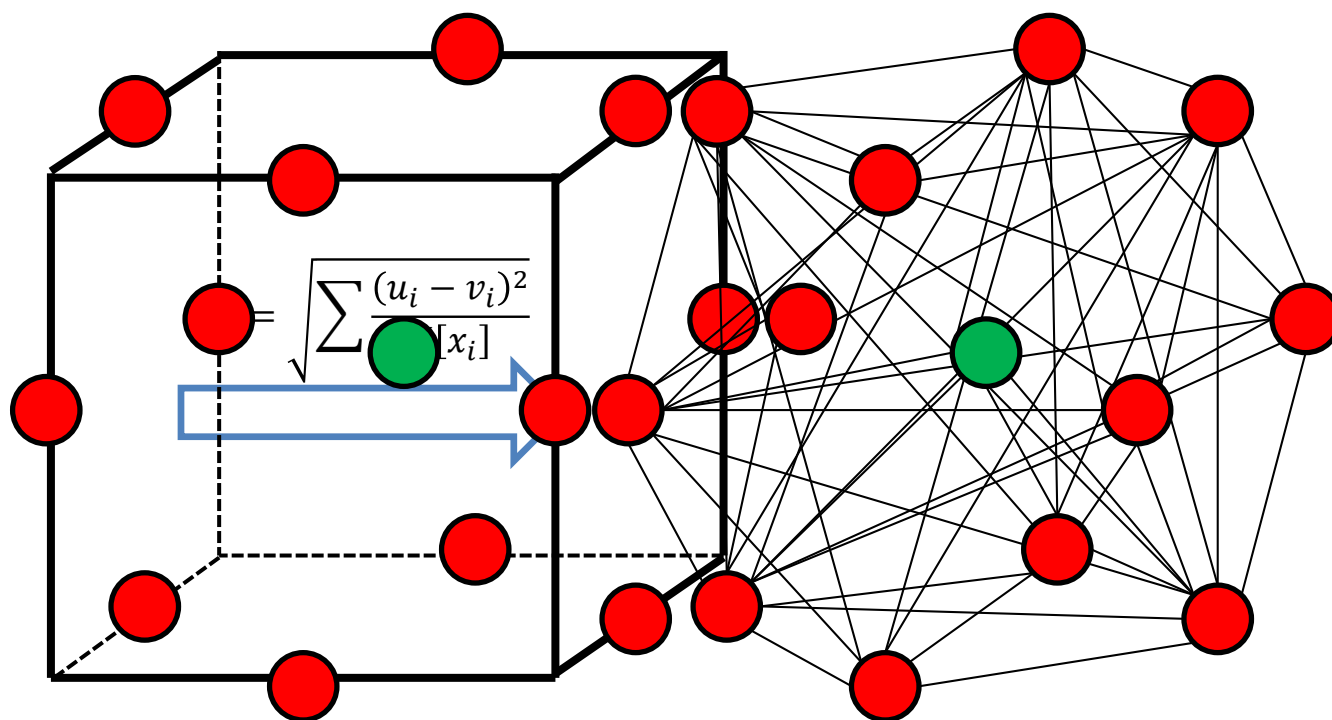


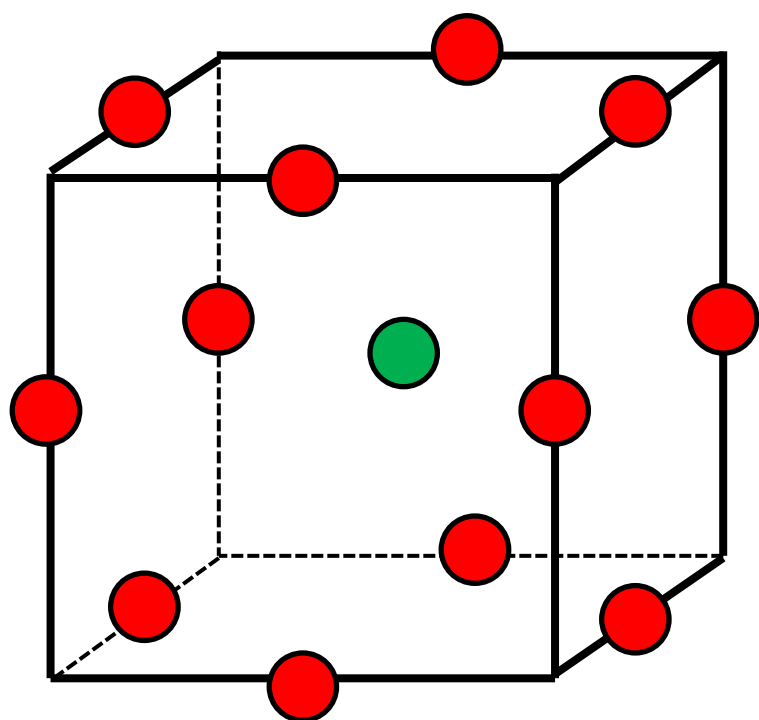
Graph Method





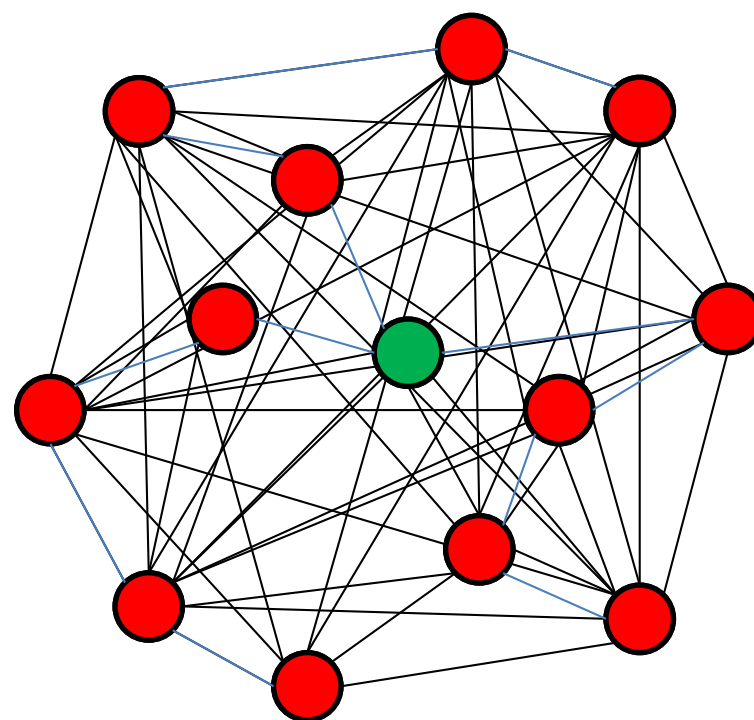
Graph Method



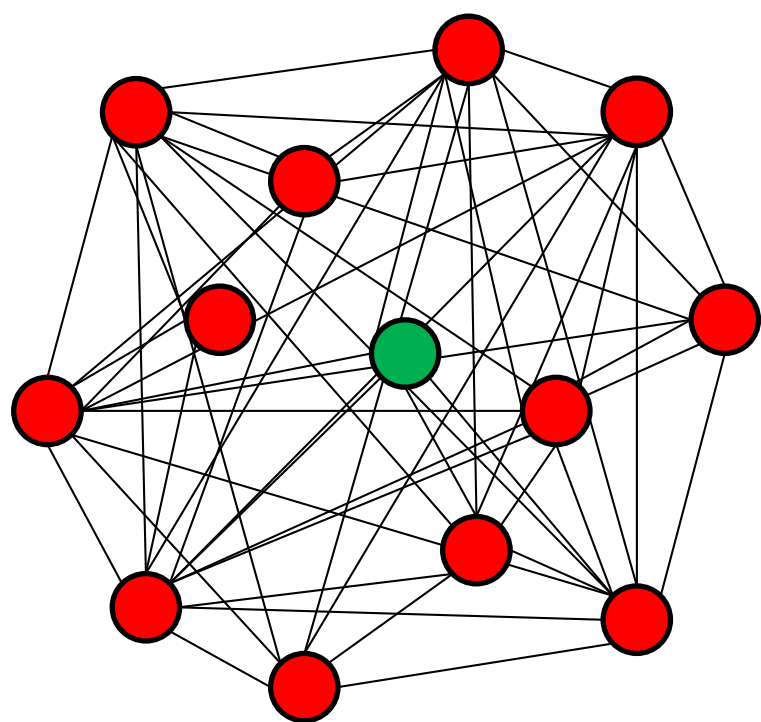


$$n(n - 1)$$

$$d_{ij} = \frac{\sqrt{\sum_{k=1}^n (u_k - v_k)^2}}{\text{Algorithm}[n]}$$

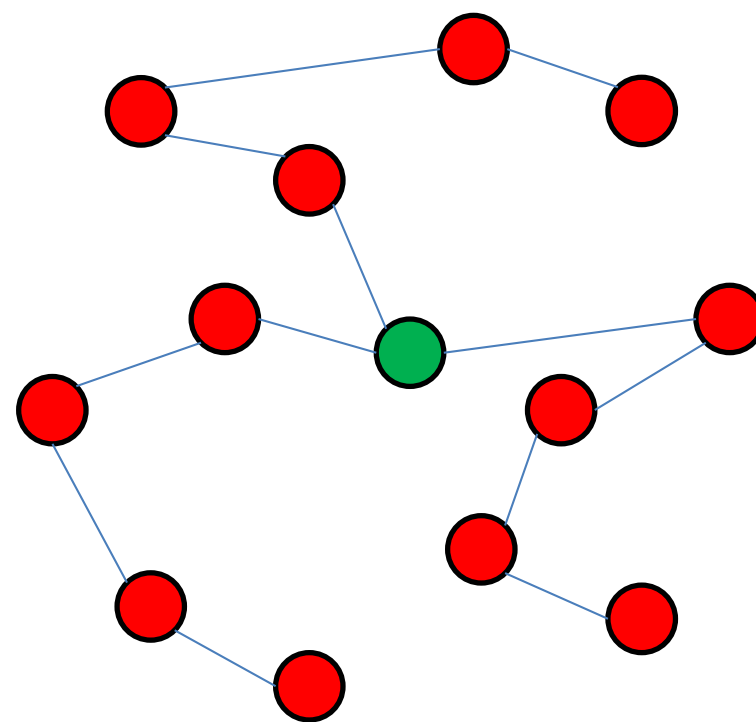
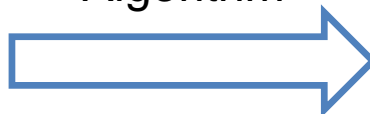


$$n - 1$$



$$n(n - 1)$$

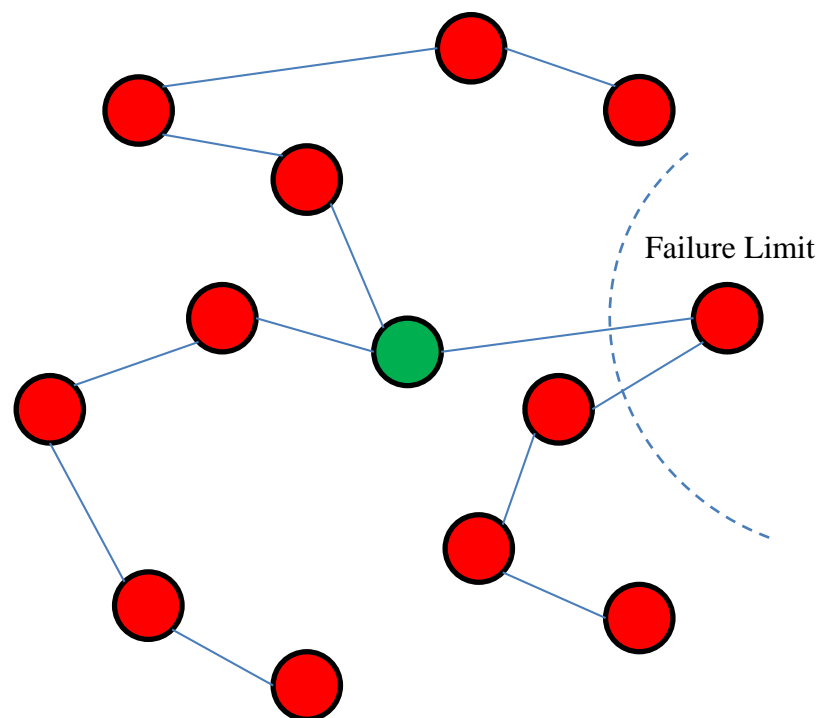
Kruskal's
Algorithm



$$n - 1$$

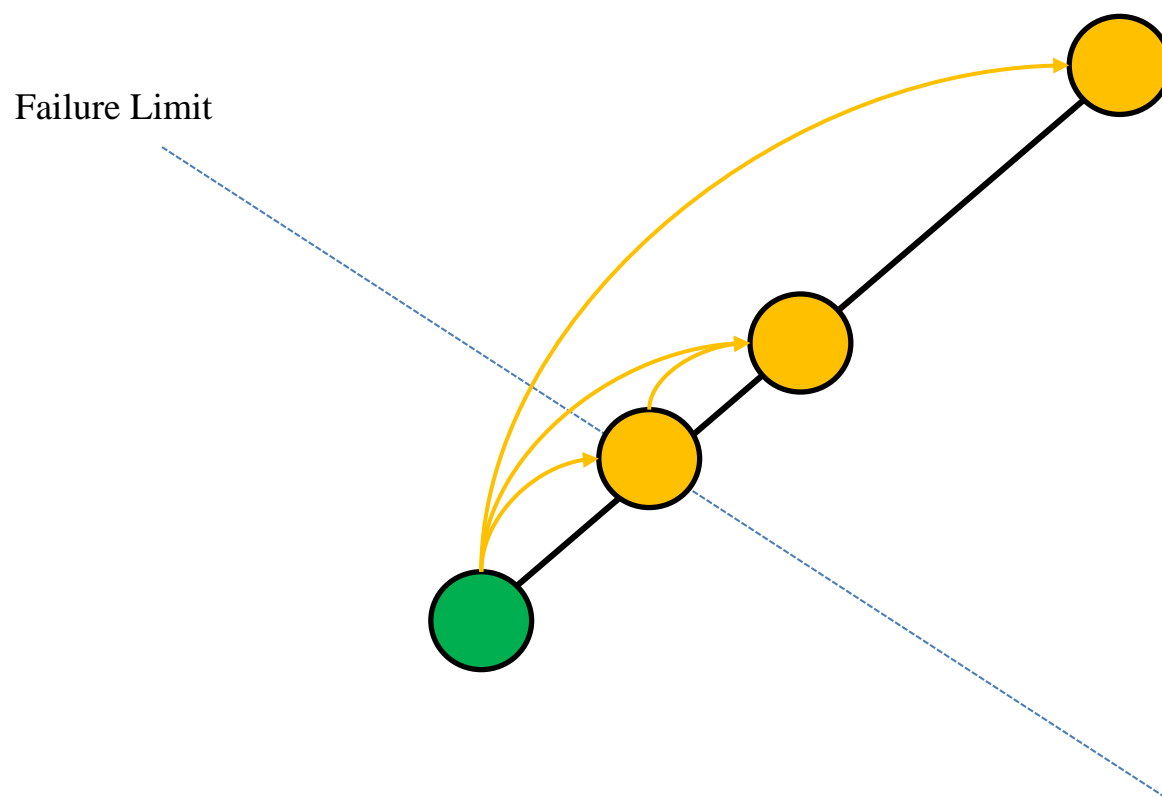


Graph Method





Halfway Nodes





Comparison Setup



◆ Comparison Metrics

- ◆ Time to gather data
- ◆ Surrogate fit from data – 2nd Order RSE
 - Coefficient of Determination - R^2
 - Root Mean Squared Error - $RMSE$

◆ Repetitions

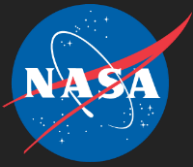
- ◆ Number of available processors
- ◆ Required completions to call a case ‘done’

◆ Graph

- ◆ Number of available processors
- ◆ Number of seed points initially included

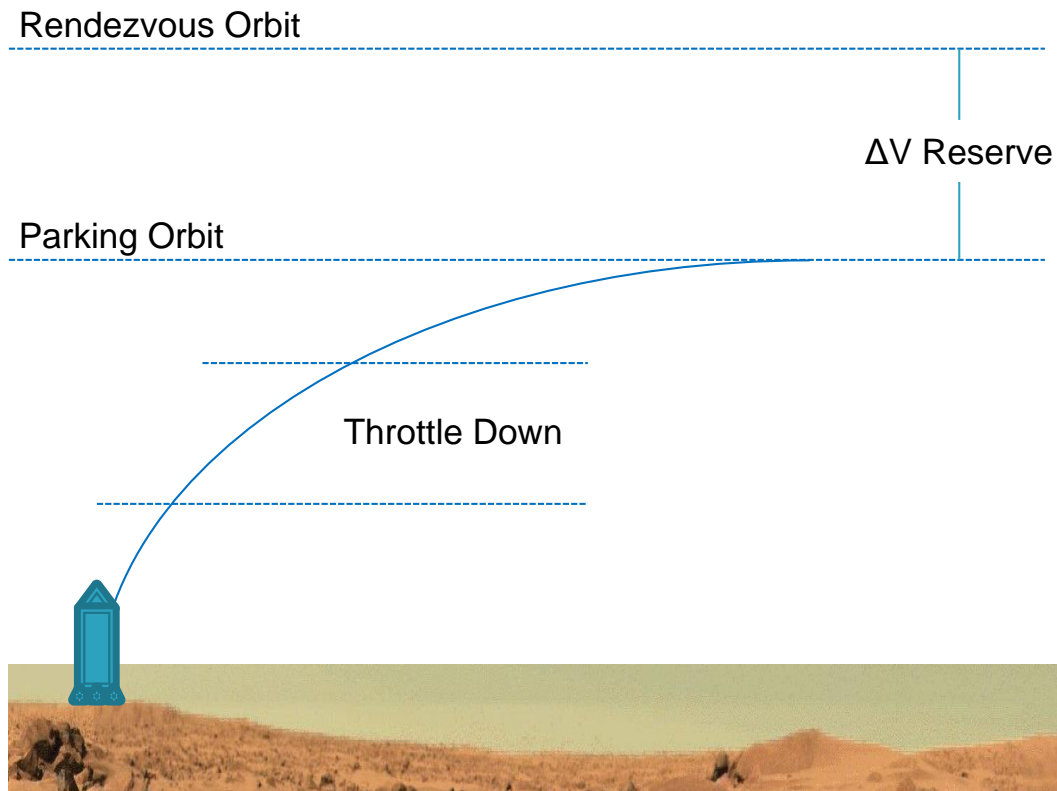
Trial	Processors	Required Completions
R1	71	1
R2	71	5
R3	71	10
R4	32	1
R5	32	5
R6	32	10
R7	16	1
R8	16	5
R9	16	10

Trial	Processors	Seed Points
G1	71	10
G2	71	15
G3	71	20
G4	32	10
G5	32	15
G6	32	20
G7	16	10
G8	16	15
G9	16	20



Comparison Example Problem

◆ Single-Stage-To-Orbit Mars Ascent Vehicle



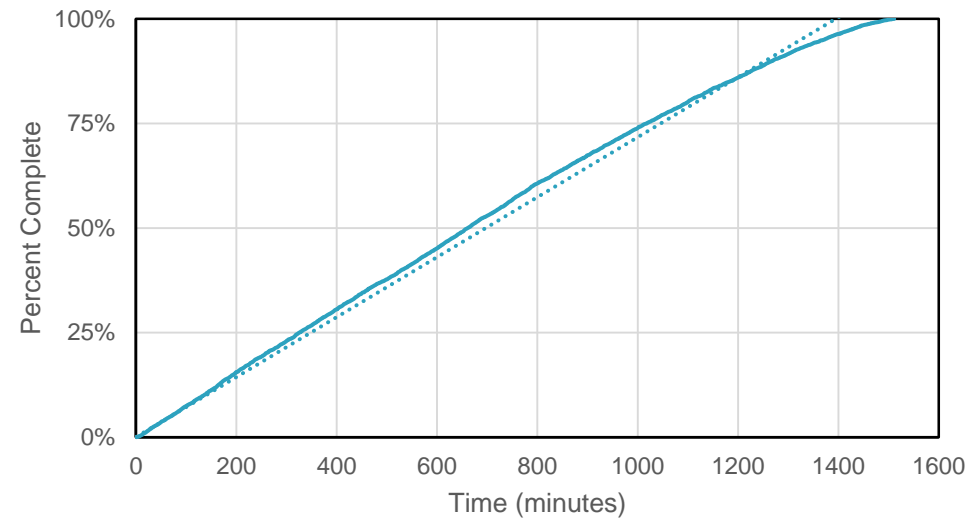
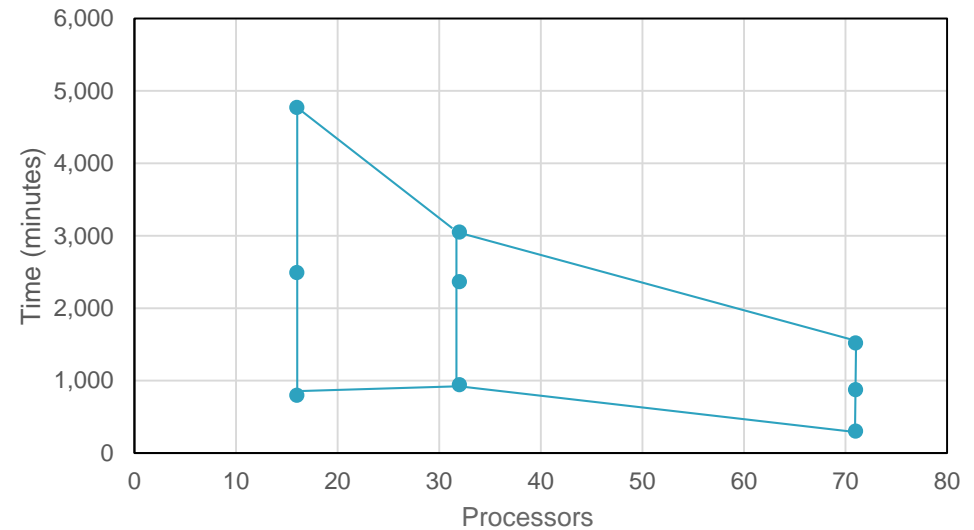
Variable	Constant
Number of Engines	3
Minimum Throttle	20%

Variable	Range
Parking Orbit Perigee	+/- 10%
Parking Orbit Apogee	+/- 10%
Rendezvous Orbit ΔV	+/- 10%
Engine Isp	+/- 10%
Engine Thrust	+/- 10%
Propellant Mass	+/- 10%
Burnout Mass	+/- 10%



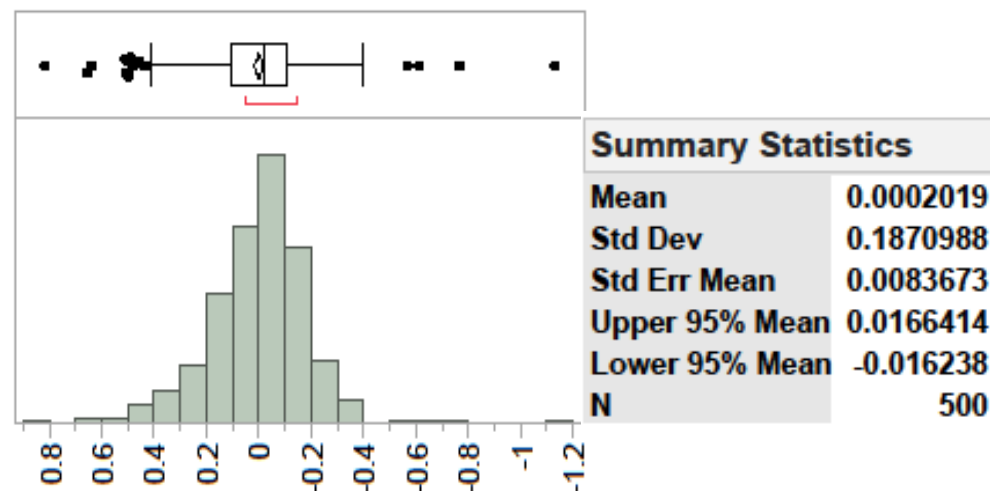
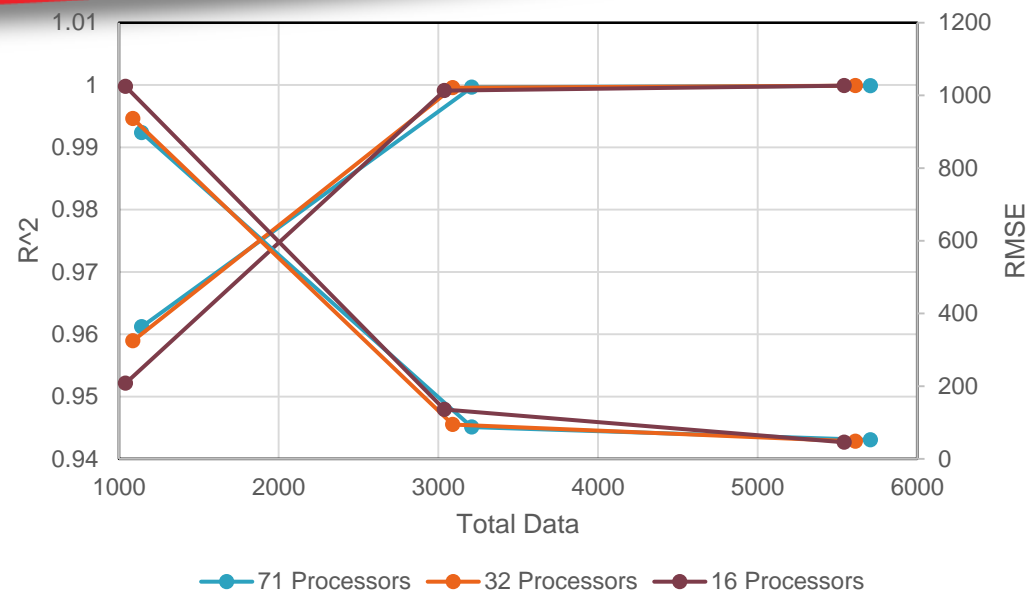
Repetitions Trials

- ◆ As available processors increases
 - ◆ Time required decreases
 - ◆ Repetitions submitted increases
- ◆ As required completions increases
 - ◆ Time required increases
 - ◆ Repetitions submitted increases
- ◆ Time history of Trial R3
 - ◆ Representative of Repetitions trials
 - ◆ “Easy” cases handled first, “Hard” cases require more repetitions, drag down convergence rate



Repetitions Results

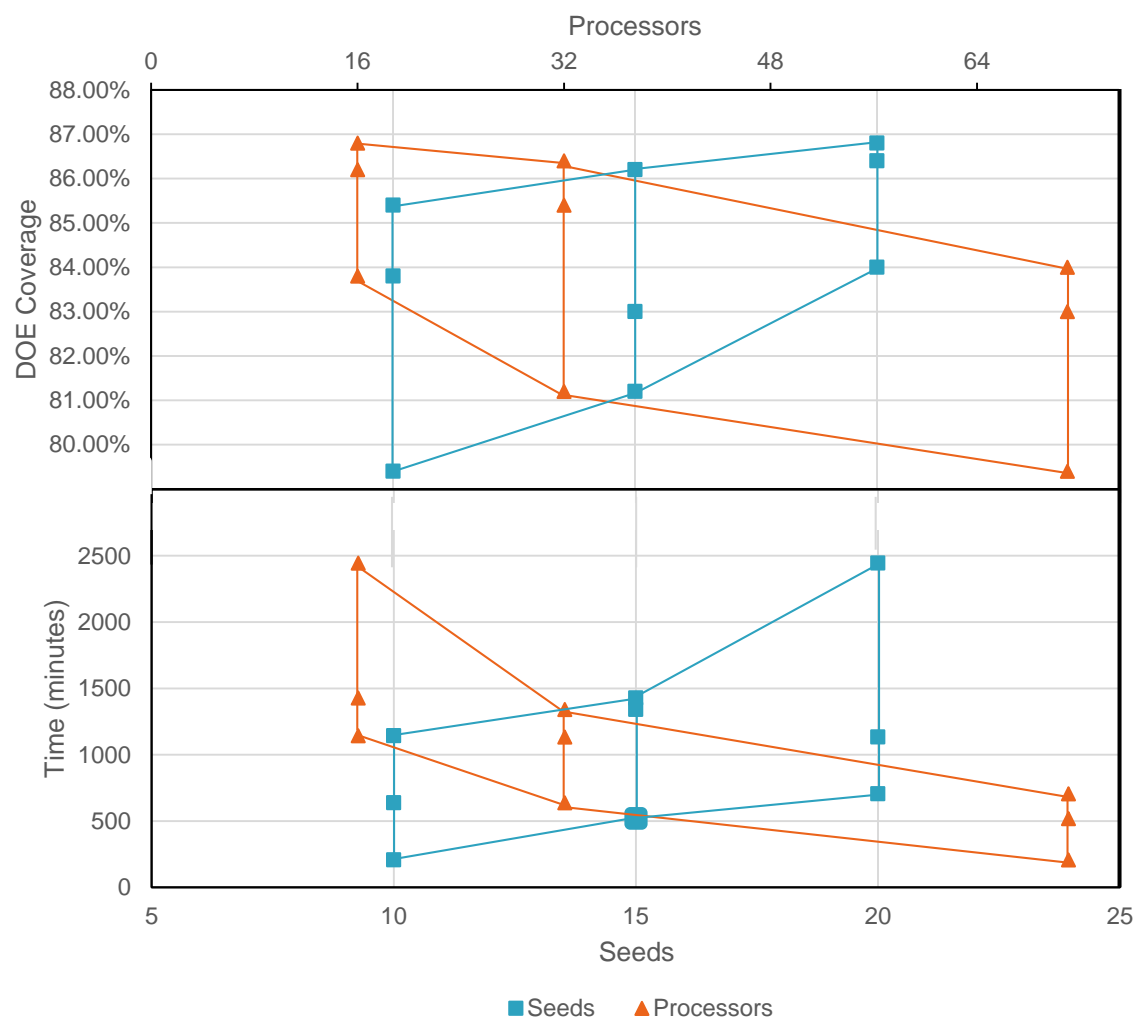
- ◆ As the amount of data available for surrogate fitting increases, the fit improves
- ◆ Surrogate
 - ◆ Best trial: $R^2 = 0.9999$, RMSE = 45.50
 - ◆ Worst trial: $R^2 = 0.95214$, RMSE = 1024.41
- ◆ In the best case, the model averages at 0.02% error





Graph Trials

- ◆ As available processors increases
 - ◆ Time required decreases
 - ◆ DOE coverage decreases
- ◆ As number of seeds increases
 - ◆ Time required increases
 - ◆ DOE coverage increases

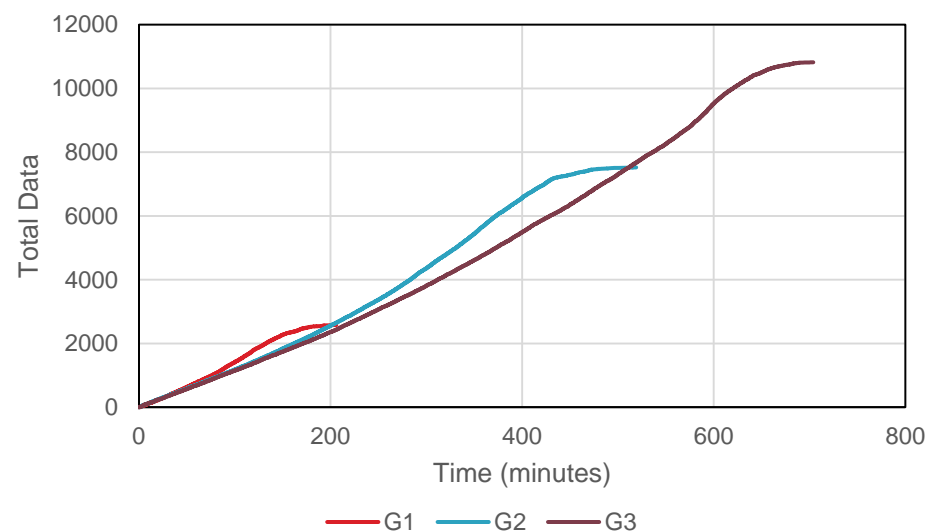
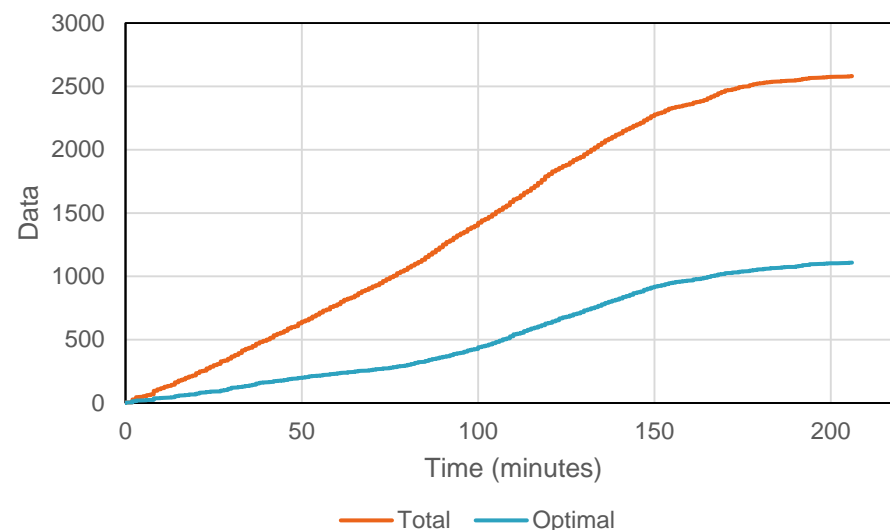




Graph Trials

◆ Time history of trials

- ◆ Total data acquisition proceeds similarly to Repetitions
- ◆ Optimal data acquisition sees a bump in rate around halfway through via the creation of halfway nodes
- ◆ Increasing the number of seeds lengthens the process as a finite number of runs can be performed simultaneously

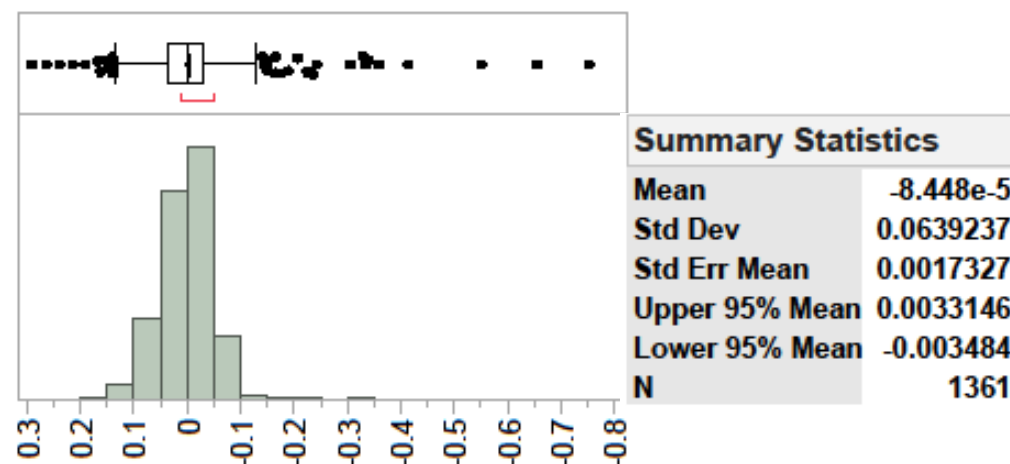




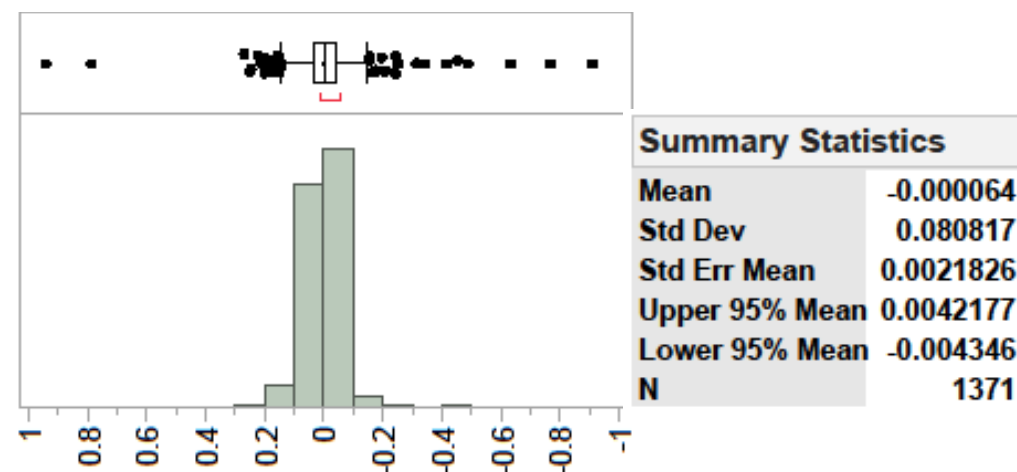
Graph Results

- ◆ Fastest graph trial returned over 2x the data returned by the fastest repetitions trial in 2/3 the time
- ◆ Surrogate
 - ◆ Best trial: $R^2 = 0.999986$, RMSE = 15.61
 - ◆ Worst trial: $R^2 = 0.999977$, RMSE = 19.90
- ◆ Best trial has average error of 0.00008%
 - ◆ Worst Graph trial outperforms best Repetitions trial

Best Graph Trial



Worst Graph Trial





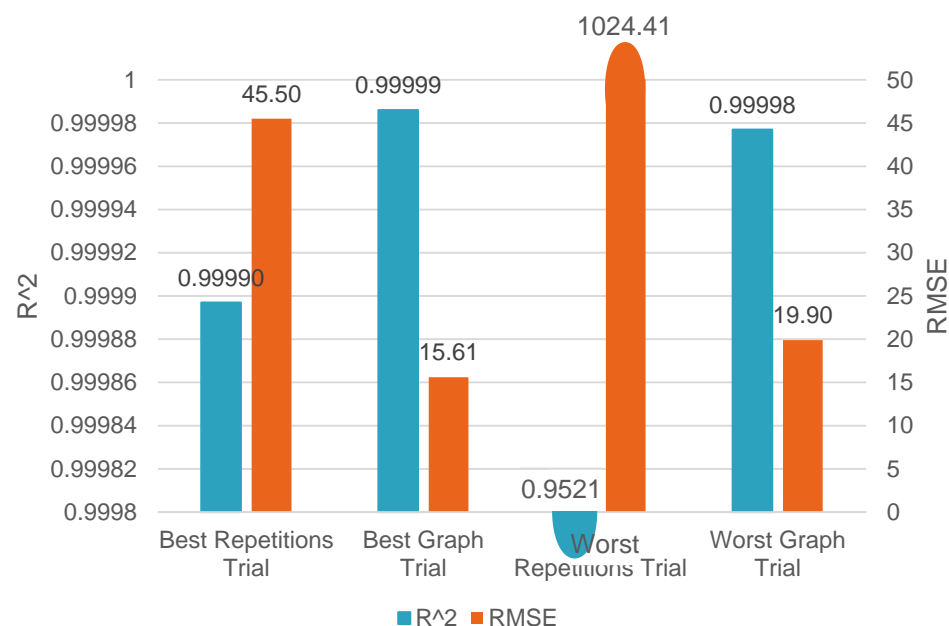
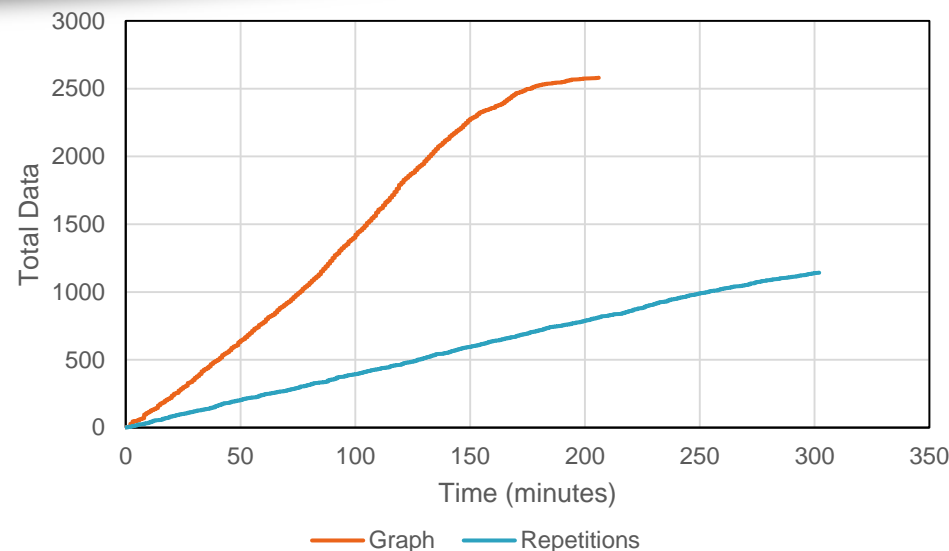
Comparison

◆ Repetitions

- ◆ Produces more data per case on average
- ◆ Output data is rough

◆ Graph

- ◆ Produced data over *3x faster*
- ◆ Worst trial outperforms best Repetitions trial



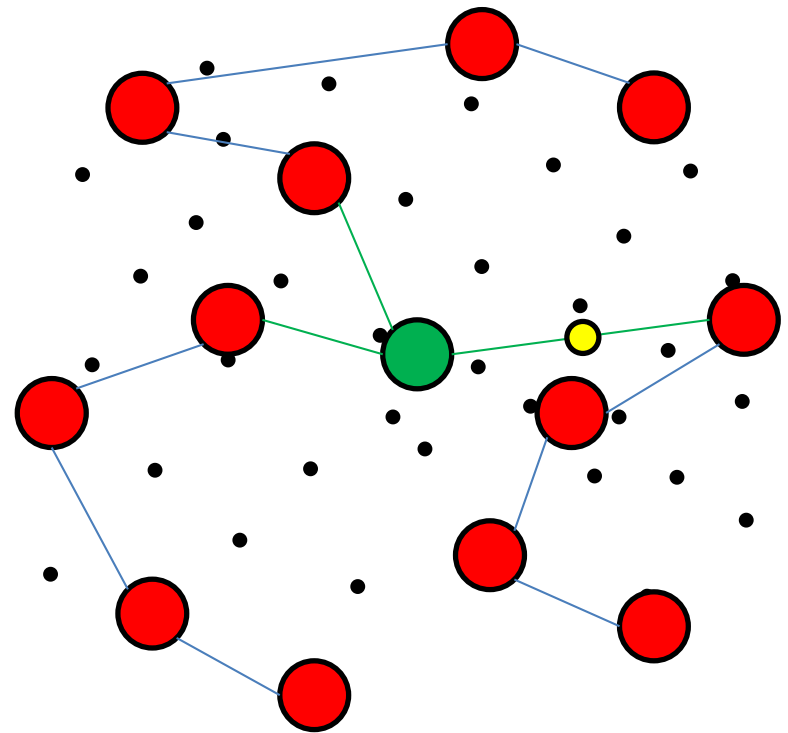
◆ Repetitions

- ◆ Virtually no upper limit to concurrent executions
- ◆ Advantageous with a small number of points where very little is known

◆ Graph

- ◆ Finite number of chainings that can occur simultaneously
- ◆ Advantageous for filling in transition regions for better surrogate fit

◆ In the end, both are necessary for large-scale trade studies





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Questions?

